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Mechanical Ventilation and Heating by a Forced Circulation of Warm Air

BY

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MECHANICAL VENTILATION AND HEATING

By a Forced Circulation of Warm Air.

Walter B. Snow.

In the combined process of heating and ventilating, a specific amount of heat is in all cases required to compensate for transmission losses to the colder outdoor atmosphere, and a certain other quantity to provide for the warming of all air which intentionally or otherwise enters the room from without.

The former amount varies with the character of the construction and the difference between indoor and outdoor temperatures. It is independent of the volume of air supplied for ventilation. The amount of heat required for tempering the air supply for ventilation *alone*, is directly proportional to its volume, and is that necessary to raise it to the temperature of the room. This is in no way available for heating, but it is all important in securing satisfactory ventilation, which, when properly provided, grows effective in proportion to the expenditure.

The relative costs of heating and of ventilation for different rates of air change are well exemplified in the accompanying chart, Fig. 1. Here as is proper, the cost of mere heating is shown to remain constant, but the necessary temperature of the admitted air decreases, while the cost of ventilation increases with the volumes admitted. Inasmuch as a cold room will not be tolerated, while a vitiated atmosphere will be endured, we have here the principal reason why so few buildings are well ventilated, namely, the cost of good ventilation.

We are not to assume, however, that where no ventilation is intended the fuel expense incurred is only that for warming. In the ordinary dwelling heated by direct means, such as stoves, steam or hot-water radiators, the effect of ventilation resulting from infiltration of air is to add at least 50 per cent. to the mere cost of warming. Where the ventilation is intentional, as with a furnace or with indirect systems, this may readily mount up to 100 per cent. and over. Therefore in the consideration of more effective systems of ventilation,

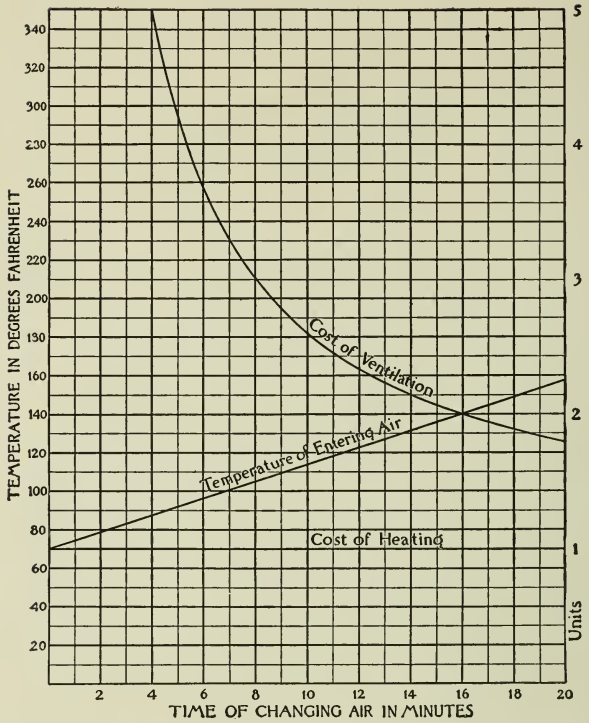


FIG. 1. RELATIVE COSTS OF HEATING AND VENTILATION, WITH DIFFERENT TEMPERATURES OF ENTERING AIR.

it is only proper to consider that portion of their expense of operation which is additional to that of existing, although inadequate, systems.

Viewed in this light, the cost of securing good ventilation is by no means great, while its improving effect upon the health amply warrants its introduction. The cost of ventilation is largely dependent upon the method employed. Natural ventilation, either through flues or by leakage, is the result of a difference in atmospheric densities and pressures due to internal and external temperature differences. Consequently the degree of ventilation usually varies with the outdoor temperature, and is lowest when that is highest. Such a method is therefore absolutely unstable.

The effectiveness of an exit flue can be increased by warming the air within by means of gas flames or steam coils, but evidently all the heat thus imparted represents an absolute loss. This loss can, however, be almost

entirely avoided by the employment of mechanical means for producing the necessary air movement. The most effective device for this purpose is a fan blower. Prof. Carpenter has shown by the accompanying table the ratio of efficiency of mechanical ventilation to that of heat ventilation, air being discharged from the top of the flue into the outside atmosphere of 60 degrees temperature.

Table showing Number of Times that Fan or Blower is more Efficient than a Chimney in discharging Air from the Top. Outside Temp., 60° F.

Combined Efficiency Fan and Engine. Condition.	Exhaust Steam Wasted.			Exhaust Utilized 11.3 Average.
	0.003 Poorest.	0.0066 Average.	0.0125 Best.	
Height Chimney, feet.	Ratio of Efficiencies.			
30	9.3	20.6	40	353
40	7	15.5	30	262
50	5.6	12.4	24	212
60	4.7	10.3	20	177
70	4	8.9	17	151
80	3.5	7.75	15	133
90	3.1	6.9	13.3	118
100	2.8	6 2	12	106

Inasmuch as the fan engine exhaust is almost universally utilized, the figures in the last column are indicative of the great degree of superiority of the fan.

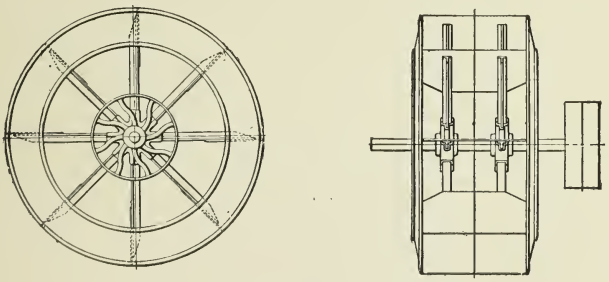


Fig. 2. Centrifugal Fan Wheel.

When a fan is employed for the purpose of ventilation, the action is positive, and air in any required volume can be handled without reference to the atmospheric conditions. Its use is imperative in buildings where the per-capita space is small and the maximum air supply is to be provided. The

term "fan," as here used, comprehends only that class of air-moving machines in which air enters the inlet in a direction parallel to the fan axis, and is discharged at the circumference in a direction at right angles to the axis. Such a fan wheel is shown in Fig. 2. The disc or propeller type of wheel, of which there are several varieties, has its place as a ventilating machine, but should be employed only where the resistances are not great. It serves best for exhausting purposes, particularly where used in connection with a heating and ventilating system in which the warm air is forced in by a fan of the centrifugal type.

A fan wheel of the latter type is almost always enclosed in a steel-plate housing with proper inlet and outlet openings. The character of the material makes possible the ready construction of any special form to meet specific conditions. Figs. 3 and 14 represent leading types.

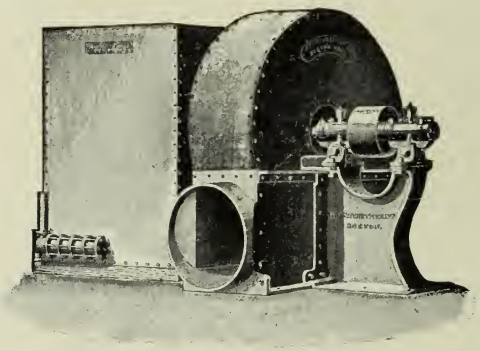


FIG. 3. STURTEVANT HEATING APPARATUS WITH PULLEY FAN.

It is manifest that air may readily serve as a vehicle for heat for maintaining the desired temperature within an apartment. Evidently the air must be preheated, and therefore the plenum or pressure method of supplying is preferable to the vacuum or exhaust method. All local or direct heating surface is eliminated from the rooms, and may be massed in connection with the fan, thereby greatly simplifying the details of installation. The heating surface thus provided almost universally takes the form of a steam coil, built up in sections as illustrated in Fig. 4.

The pipes, usually one inch in size, are here set 2⅛ in. on centres, thus providing a free area for passage of air equal to about 40 per cent. of the gross area of the face of the section. The air passing through such a heater must be

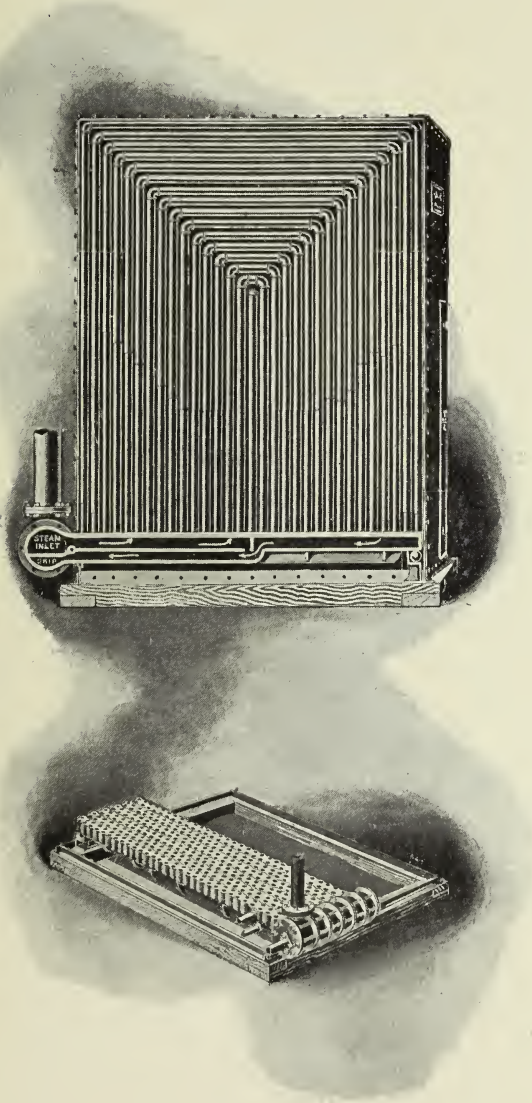


FIG. 4. STURTEVANT HEATER SECTIONS.

warmed by a contact. The increment due to radiation is very slight. Therefore the arrangement of pipes here shown, which thoroughly breaks up all currents, best serves the purpose by insuring intimate and constantly changing contact.

The compactness of this construction is shown by the fact that within the space measured by 6 ft. in length, 7 ft. in height and 7½ in. in thickness there may be massed nearly 1,000 lineal ft. of one-inch pipe. Such construction readily lends itself to manifold arrangements in connection with fans of various types. The most important feature of this type of combined heating and ventilating apparatus, familiarly known as a hot-blast apparatus, lies in the fact that the rapid movement of air across the heated surfaces renders them vastly more efficient than when exposed in still air. In other words, far less surface is required for the same heat transmission.

The effect of moderate rates of air movement, as determined by Prof. Carpenter for ordinary indirect radiators, shows that with a temperature difference of 150 degrees and direct radiation in *still air*, the heat transmission per hour per degree difference is about 1.85 B. T. U. per square foot, while with a velocity of 10 ft. per second it is increased to about 6 B. T. U. In other words, the heating surface becomes over three times as efficient.

In a hot-blast apparatus consisting of a fan and heater like those just illustrated, the heat transmission, when the air velocity is 1,200 ft. per minute, is on the average about 10 B. T. U., or over 5 times as much as in the case of direct radiation. That is, a hot-blast apparatus need contain only one-fifth the surface required to secure a given result with direct radiation.

The effect of higher velocities and of different steam pressures is well shown by the results of tests of Sturtevant heaters in connection with fans. The relative condensation increases with both of these factors as shown by the curves for 5 pounds and 80 pounds in Fig. 5. But as indicated by the other curve, the relative temperature increment with a given steam pressure decreases with the velocity. This is the natural result of moving a larger volume of air across the heating surface, and decreasing the time of contact. Disregarding the expansion by heat, the volume is proportional to the velocity; therefore we may determine the relative heat transmission by multiplying the relative velocity by the given condensation.

The rate of condensation is naturally dependent upon the temperature difference between air and steam, and is therefore greatest with the maximum difference. Hence the less the depth of the heater, the less the total temperature increment of the air, but the more rapid the rate of transmission from steam to air. With increasing depth of heater, or of the number of rows across

which the air must be passed, there is a corresponding decrease in the average condensation per square foot. The surface first exposed to the air of course

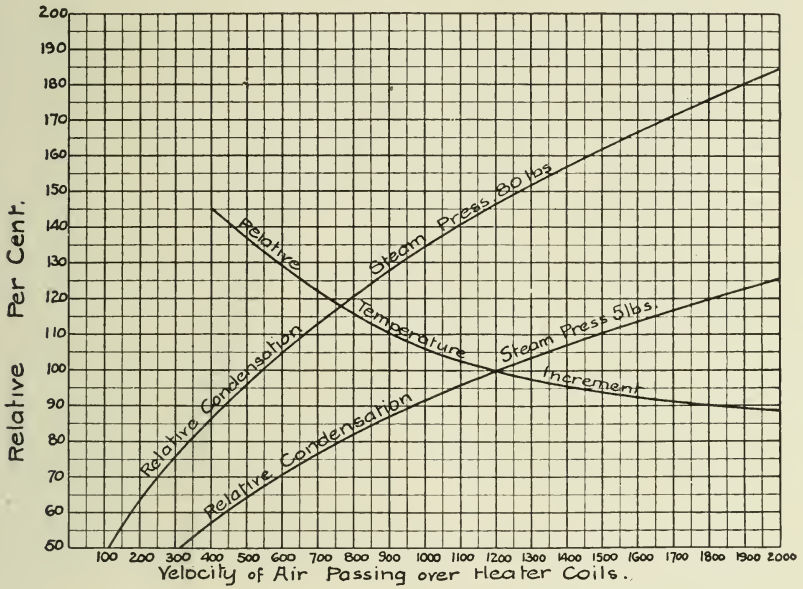


Fig. 5. Relative Temperature Increment and Condensation, for Different Velocities of Air in Sturtevant Heater.

continues to maintain the same efficiency, but the surfaces subsequently passed over are progressively exposed to smaller and smaller temperature differences.

The exact conditions in a Sturtevant heater operated in connection with a fan which produces a mean air-velocity flow of 1,200 ft. per minute through the free area of the heater are presented in Fig. 6.

From these and the preceding curves it is evident that the greatest surface efficiency is secured with the highest velocity of air and the least depth of heater. Practically, however, it is necessary to limit the velocity of the air and to make the heater of sufficient depth to give the required temperature increment to the air.

Beyond a certain point the low efficiency of added surface does not warrant its introduction. Furthermore, in the case of a building like a factory, so sparsely occupied that the problem of heating is of primary importance, the greatest economy in this process will be secured when the air volume supplied

is the least, and its temperature is the highest. In the ordinary building of this type, the air which is actually required as a vehicle for the heat usually

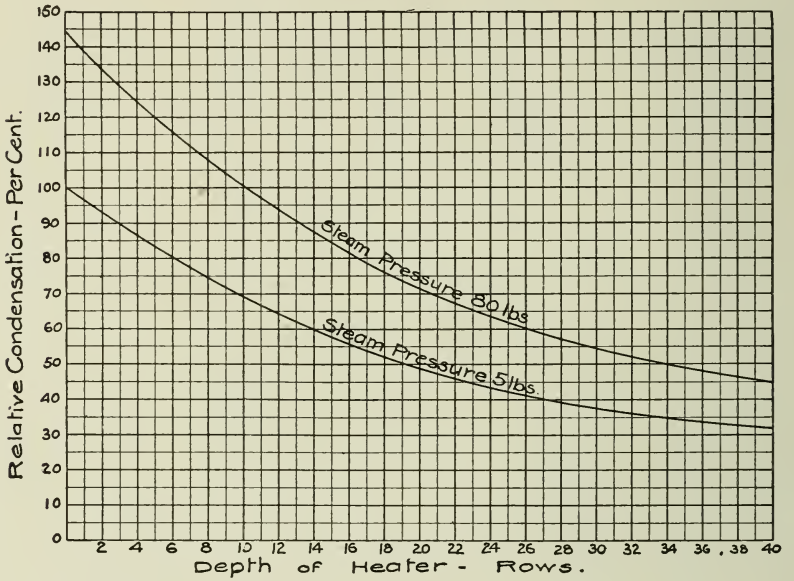


FIG. 6. RELATIVE CONDENSATION IN DIFFERENT ROWS OF STURTEVANT HEATER. VELOCITY OF AIR, 1,200 FEET PER MINUTE.

exceeds what is necessary for the purposes of ventilation. As all air supplied to the building must necessarily escape from it at the mean internal temperature, the opportunity for saving is apparent.

A fair compromise between extreme conditions and that generally adopted in practice consists of an arrangement in such a building whereby the fan is operated at a circumferential speed approaching 5,000 ft. per minute. The fan engine exhaust is utilized. The mean air velocity through the heater is about 1,800 ft. per minute, and the heater is of sufficient depth to warm the air to about 140 degrees in zero weather.

The design and manner of application of such an apparatus, and the method of air distribution employed in this system, must of necessity depend upon the character of the building, its surroundings and its uses. The ordinary structure devoted to manufacturing purposes presents the simplest of all problems. As a rule the per-capita space for the operatives is large, and

the heating is to be considered as of paramount importance, while the ventilation, although sufficient with the blower system, is in a sense incidental. In fact, ample ventilation may usually be secured by allowing the fan to draw its supply from the building itself, thereby simply turning the air over and over, and merely adding to it the heat necessary to offset the transmission and leakage losses. To this end it is most desirable that the apparatus be placed as near the centre of the building as possible, so that the air may be drawn back to it from all sides. Such location also simplifies the distributing system and reduces the cost.

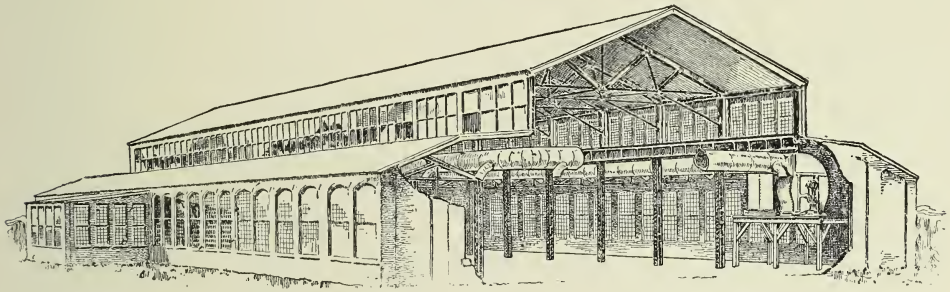


FIG. 7. SIEMENS & HALSKE ELECTRIC CO. OF AMERICA, CHICAGO, ILL.

From the apparatus the air may be conducted by underground ducts or overhead pipes to its proper destination. Inasmuch as the best results are secured by discharging the heated air above head level in a horizontal or slightly downward direction and towards the outer walls, it is usually most convenient in a one-story factory building to carry the piping overhead in the manner shown in Fig. 7.

In this case the apparatus is supported upon a platform in one corner of the building, because of the proximity of the exhaust-steam supply. The hot-air piping is placed overhead, and carried entirely around the interior. Air as a rule is returned from the building, but the large window area with consequent leakage is sufficient to bring about a constant air change to meet all purposes of ventilation.

The fan in such a building is usually operated at a maximum speed corresponding to a circumferential velocity of the wheel of about a mile a minute. The velocity of discharge through the outlet in the casing then approximates 3,500 ft., which, however, will be decreased in proportion to the resistances of the piping system. Although low velocities are evidently conducive to an

economical movement of air, the objection to large ducts necessarily limits their size, while the customary utilization of the exhaust steam from the fan engine reduces the possible saving to a very small amount.

For factory heating, the main discharge pipe leading from the fan is generally of the same area as the outlet. The resistance of branches is compensated for by increased area, so that the aggregate area of the outlets will range from 25 to 40 per cent. in excess of the fan outlet, and the corresponding discharge velocities will be decreased to 2,800 or 2,500 ft., or even lower where the resistances are great.

It is frequently possible in a building of the character just presented, to secure satisfactory circulation of the air with a limited extent of ducts by discharging the air at high velocity, and thus compelling it to continue its direction of movement for a considerable distance without the use of conducting pipes. The possible simplicity of this construction is largely due to the character of the work carried on within the building, especial refinement in the manner of distribution being unnecessary where the operatives are actively employed.

There are other cases, however, where, owing to the presence of obstructions within the building, the air can be forced only a short distance from the pipe outlet, and local distribution is necessary. Such is the condition presented in the ordinary passenger-car paint shop. Here the air is discharged directly downward toward the floor through pipes extending down between the cars. Not only is the building effectually heated, but the time of drying the paint upon the cars is materially reduced.

A similar problem presents itself in the case of a locomotive round house, where the fan system serves a double purpose. It effects a general heating of the building by discharging the air from overhead pipes toward the walls on either side, and at the same time is utilized as a means of rapidly melting the snow and ice from the running gear of the locomotives. This is done by conducting a portion of the air to the working pits.

In the familiar gallery type of manufacturing building the problem of air distribution becomes somewhat more complicated because of the impossibility of carrying pipes across the central space through which the crane travels, or of successfully forcing the air across this space. It therefore becomes necessary to provide for distribution upon both sides. Either of two methods may be employed. In the former the apparatus discharges the air through underground ducts to galvanized-iron flues, placed against the walls on both sides of the building. From these the air is delivered along the walls above head level.

In the second arrangement, illustrated in Fig. 8, two independent appa-

ratuses are employed. They are placed in the galleries midway of the length of the building, and each delivers the air to a double system of pipes, one for each floor, whence it is discharged toward the outer walls. This is an ideal arrangement for the return and reheating of the air.

In any installation the first cost is dependent upon the number of individual units in the heating system. In the ordinary building a single apparatus is usually most desirable, but when numerous connected structures are to be warmed, it is generally expedient to divide this into a number of independent units.

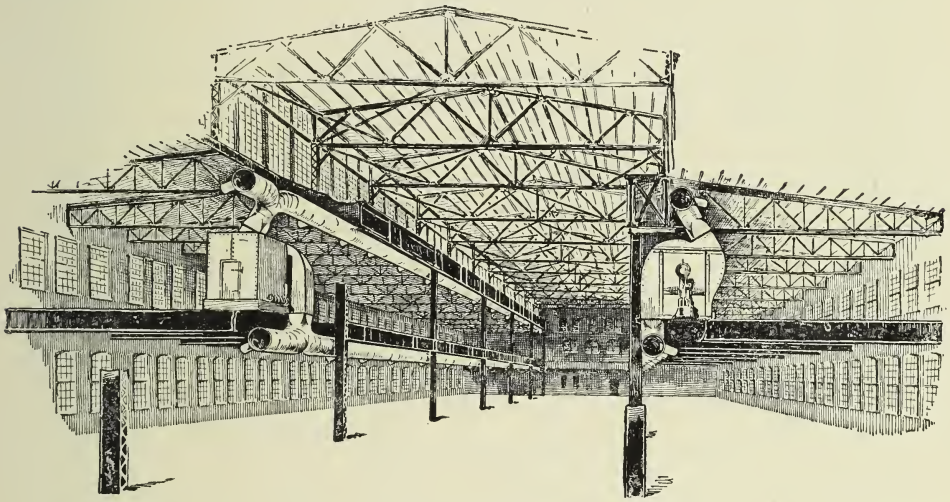


FIG. 8. LINK BELT MACHINERY CO., CHICAGO, ILL.

In buildings of more than one story, the simplest arrangement for heating consists in placing the apparatus on the lower floor or in the basement, and delivering the air into one or more vertical flues from which it is discharged through suitable outlets upon the several floors. In a wooden structure, or in one of brick or stone which is already built, such distribution must be made by means of galvanized iron pipes.

The simplest possible arrangement consists of a single upright galvanized-iron flue, immediately beneath which the apparatus is placed so as to deliver the air directly upward into the base of the flue. Upon each floor the requisite number of outlets are provided at or near ceiling level and the air discharged therefrom towards the outer walls. In the case presented in

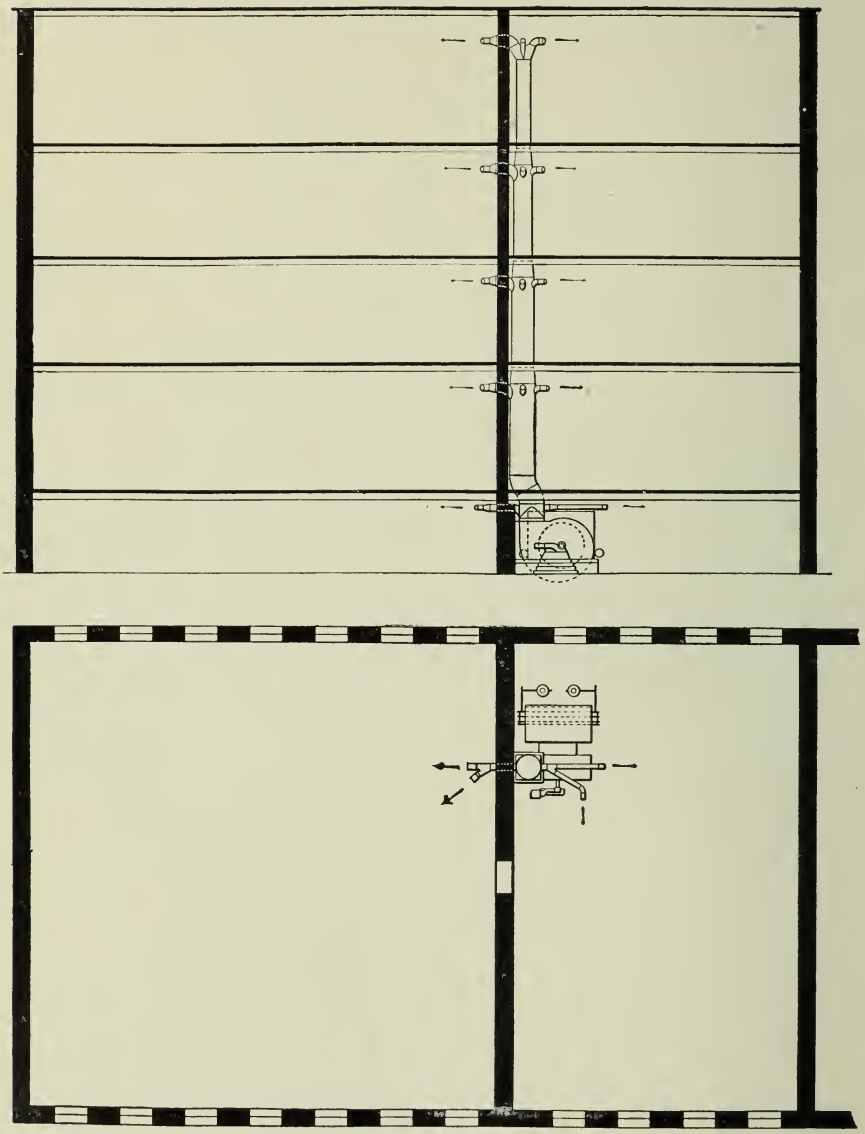


FIG. 9. ROCHESTER OPTICAL CO., ROCHESTER, N. Y.

Fig. 9, adjacent rooms are thus heated with the minimum amount of distributing pipe. It is evident that a similar arrangement may be introduced within a building of the same floor area, but without such partition wall, in which case the pipe would be located practically in the centre. Or distribution may be made from a vertical pipe placed against one of the walls, the effect then being equivalent to that secured within that portion of this particular building in which the pipe is shown to be located.

As the building becomes more extended in its character, it becomes necessary with a single standpipe system to somewhat extend the branches so as to

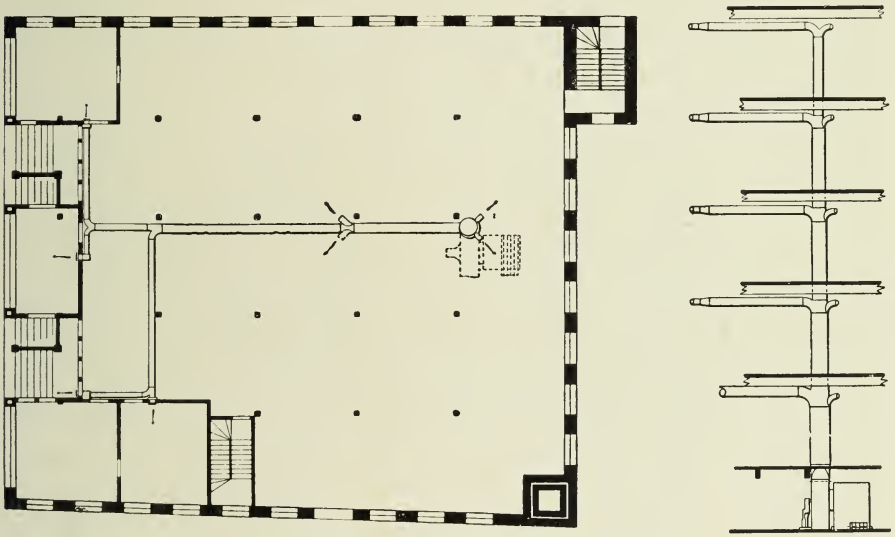


Fig. 10. James Phelan, Lynn, Mass.

convey the air to a greater distance from the standpipe, as is clearly shown in Fig. 10. The apparatus is here placed in the basement and discharges directly upward into the standpipe. Upon the first floor the branch pipe is extended and subdivided so as to heat the individual offices on that floor, while upon the other floors the horizontal branch is only of moderate length. In a long building in which a single standpipe is adhered to, a greater extent of the piping system on each floor may be made, as in the case of Fig. 11, where the standpipe is carried up outside of the building, but thoroughly protected, and the horizontal pipes on the various floors are kept comparatively near the wall. Evidently a similar arrangement can be made if the standpipe is carried up in

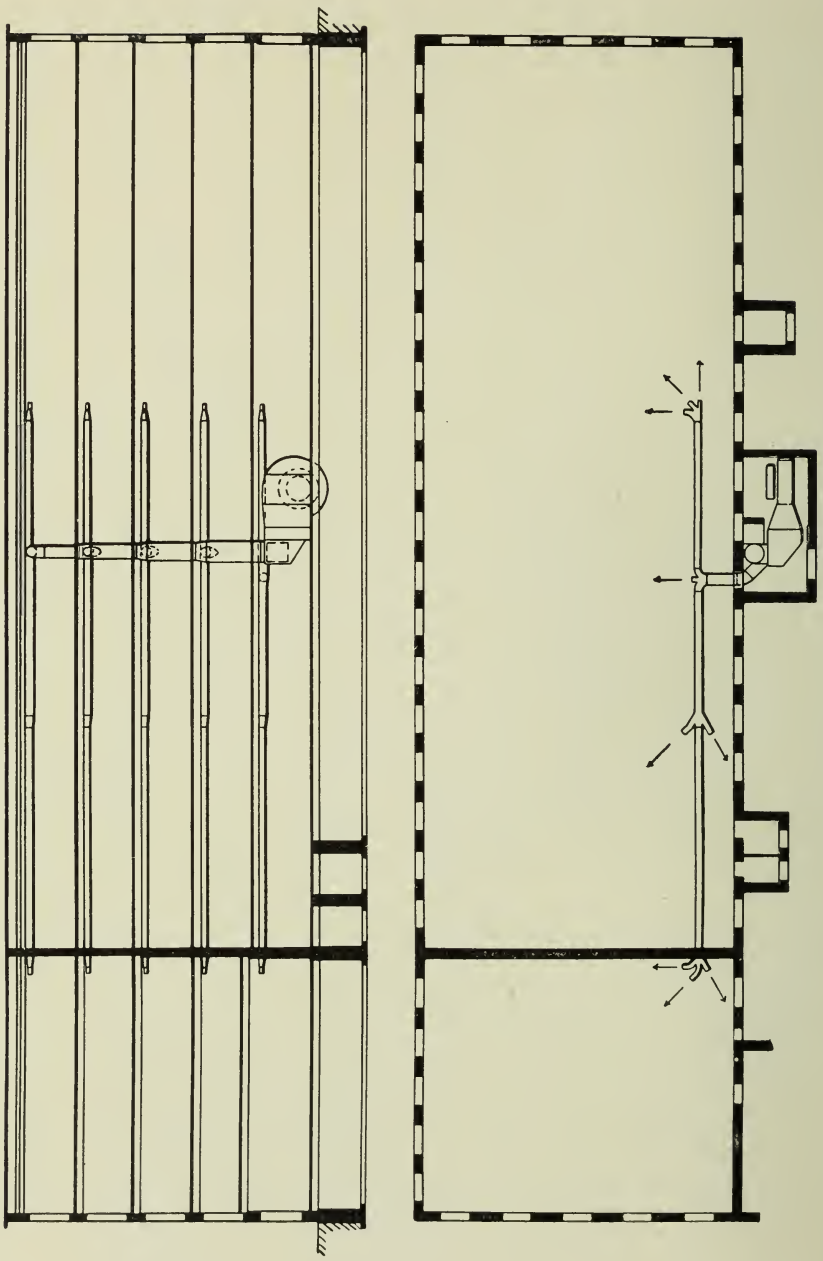
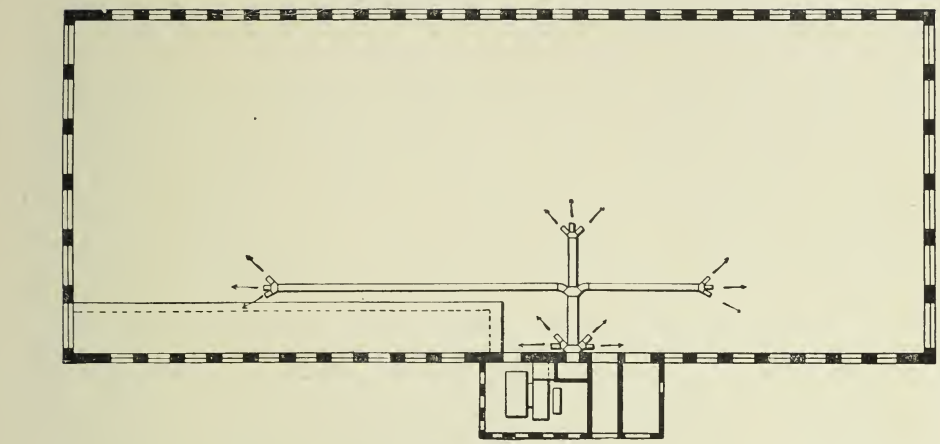


FIG. 11. MONTMORENCY COTTON MILLS, MONTMORENCY, P. Q.



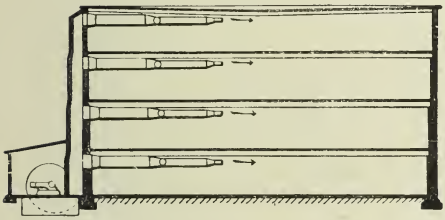


FIG. 12. D. M. OSBORNE & CO., AUBURN, N. Y.

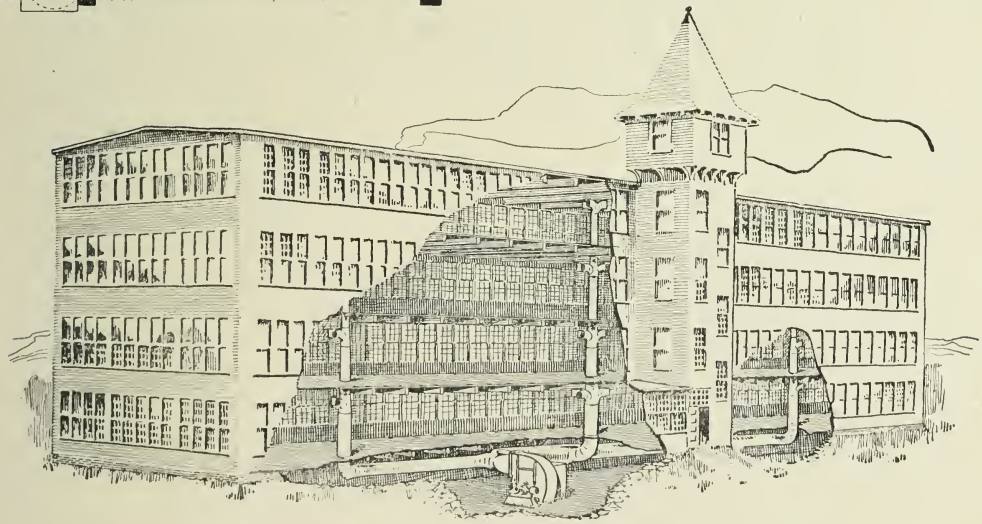


FIG. 13. C. H. MOULTON & CO., BROOKFIELD, MASS.

the centre of the building and the pipes extended lengthwise therefrom on each floor.

Where the available floor area will permit, fully as simple an arrangement is that presented by Fig. 13 in which three individual standpipes are provided, each discharging air through several outlets near ceiling level and always towards the outer walls. The apparatus used in this instance consists of a fan of the ¾-housing type with a portion of the scroll built in the brick foundation, a heater of the construction previously illustrated in Fig. 4, and a horizontal engine direct connected to the fan shaft, all as illustrated in Fig. 14.

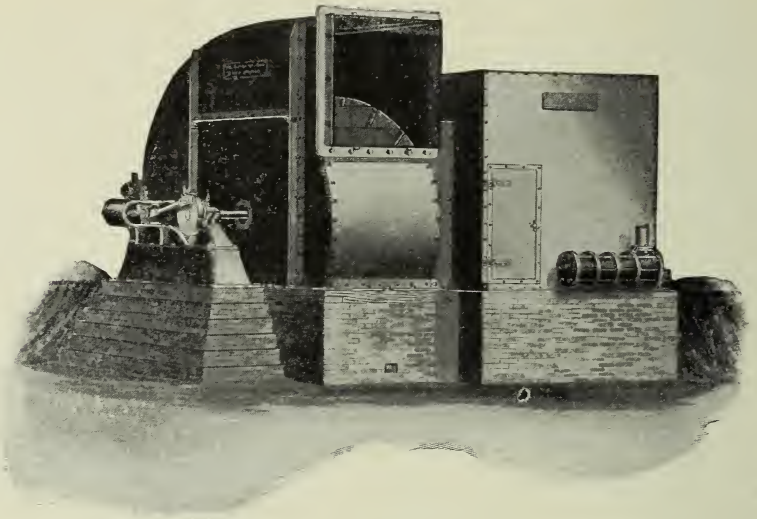


FIG. 14. STURTEVANT HEATING APPARATUS WITH ¾-HOUSING STEAM FAN.

In a new brick building, convenience can be secured by distributing the air from one or more brick flues built against the wall of the building. If these are provided in sufficient number they require no distributing pipe connections, but if economy is sought by providing a single flue, then it becomes necessary to obtain satisfactory distribution on each floor in some such manner as is shown in Fig. 12, in which an individual system is provided at the ceiling of each floor. Where the building is of less extent, a special deflecting outlet may be placed upon the opening in the flue on each floor and serve to effectually distribute the air.

In a new brick structure of reasonable size, the best arrangement consists

in building a series of pilaster flues against the outer wall along one side of the building, from each of which the air is discharged toward the opposite side through openings at eight or more feet above the floor. The modern textile mill with its symmetrical design is manifestly adapted for such an arrangement.

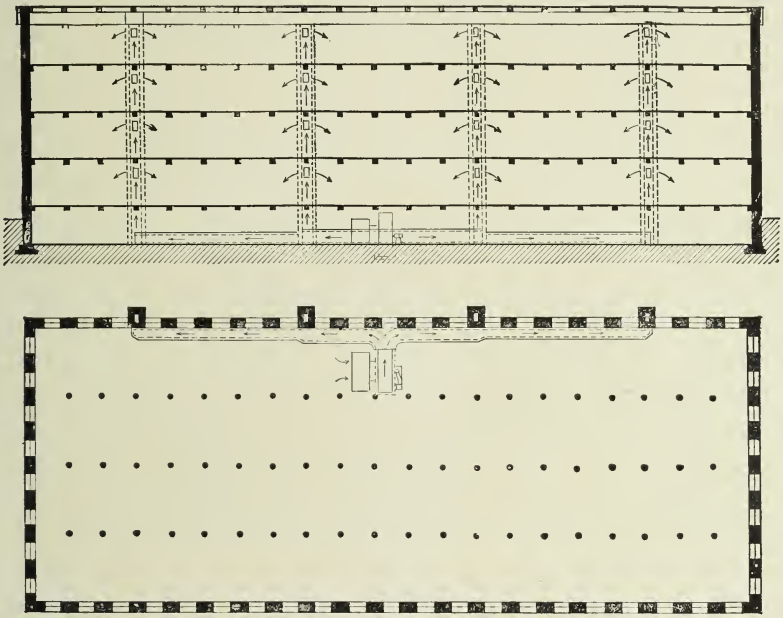


FIG. 15.

The apparatus is usually placed in the basement, near the centre of the building, and discharges the air into a duct running along one side of the building, and communicating with the bases of the flues, as illustrated in Figs. 15 and 16.

These flues add but little to the cost of the building. Each opening or outlet is provided with a special form of damper, Fig. 17, which serves the double purpose of deflecting the air toward the room when open, and of preventing admission when closed.

The large amount of moving machinery, pulleys, shafting and belts in such a building serves to thoroughly break up all air currents and effectually distribute the air. The equality of temperature maintained is evidenced by the accompanying average results and readings taken at random from a record kept at the West Weave Shed of the Pacific Mills, Lawrence, Mass.

Temperature and Humidity in West Weave Shed, Pacific Mills, Lawrence, Mass.

Date.	Time.	Temperature.					Humidity.
		East End.	Middle.			West End.	
			Floor.	Head High.	Ceiling.		
1889.		Degrees.	Degrees.	Degrees.	Degrees.	Degrees.	Per Cent
Feb. 7	9:15 A. M.	70	70	70	71	68	65
Feb. 7	1:15 P. M.	68	69	68	70	66	64
Feb. 7	6:15 P. M.	70	71	71	72	66	66
Feb. 8	6:45 A. M.	70	69	71	73	66	61
Feb. 8	2:45 P. M.	73	74	75	76	72	68
Feb. 9	7:25 A. M.	70	69	71	72	66	75
Feb. 11	10:30 A. M.	68	68	69	68	68	75
Feb. 11	5:30 P. M.	72	72	73	72	69	63
Average		70.12	70.25	72.25	71.75	67.64	67.12

Comparative Cost and Running Expenses for Heating, Ventilating and Moistening System, Globe Yarn Mills, Nos. 1 and 2, From Oct. 15, 1888, to March 15, 1889.

Cost of Introduction.	No. 1. *	No. 2. †
First cost of heating and moistening system	$4,600.00	
First cost heating, ventilating and moistening system		$4,000 00
Cubic contents, cubic feet	1,103,852	1,316,520
Average temperature	70°	78°
Cost of system per 1,000 cubic feet	$4.17	$3.04
Ratio	100	73
	137	100
Running Expenses.		
Coal burned for heating	317,100 lbs.	
Coal burned for moistening	58,500 lbs.	
Coal burned for both heating and moistening	375,600 lbs.	
Coal burned for heating, ventilating and moistening		286,900 lbs.
Coal burned per 1,000 cubic feet	340.26 lbs.	217.92 lbs.
Ratio	100	64
	158	100

* Overhead direct radiation and Garland moistening system.

† Sturtevant system of heating, ventilating and moistening.

The mill was 440 ft. long and 70 ft. wide. The west end was entirely exposed to the sweeping winds from the Merrimac River, while the east end contained the lighting plant and heating apparatus. The openings for air admission were only five in number on each floor, placed along the south side of the mill, and aggregating 2.37 square inches area per 1,000 cubic feet of space.

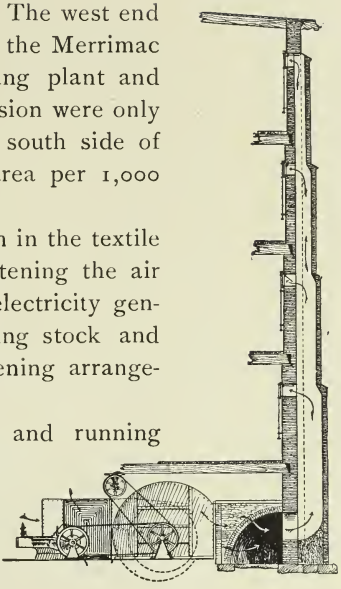


FIG. 16.

An important advantage of the blower system in the textile mill lies in the opportunity presented for moistening the air so as to offset the serious effect of frictional electricity generated by the motion of belts, pulleys, running stock and machinery. In a direct-heated mill the moistening arrangements are frequently very expensive.

An interesting comparison of first costs and running expenses in two nearly identical mills belonging to the same corporation is here presented. Mill No. 1 was heated by direct radiation, and a complete independent moistening system was introduced. In Mill No. 2 the blower system was installed for the combined purposes of heating, ventilating and moistening. The cubic contents of the latter building was the greater, as was also the exposure. Nevertheless, the first cost of the system per 1,000 cubic feet was only 73 per cent. of that in the No. 1. Mill, while the temperature maintained was much higher, with a fuel expenditure of only 64 per cent. of that required in Mill No. 1. Although the air supply was taken from the building, the natural leakage was so great as to provide ample ventilation.

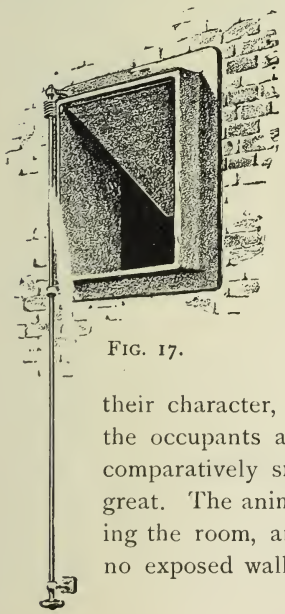


FIG. 17.

In all the buildings of the types thus far presented the ventilation has been of secondary importance, but in a large class of structures, more or less public in their character, such as schools, churches, theatres and halls, where the occupants are more or less closely seated, the per-capita space is comparatively small, and the vitiation by respiration proportionately great. The animal heat of the occupants has a material effect in warming the room, and in a building like a theatre, which has practically no exposed walls, the problem of artificial heating is thereby reduced

to relative insignificance. The ventilating problem, however, assumes correspondingly increased importance, and it becomes necessary to provide means of supplying air in large volumes, properly tempered, admitted at such low velocity, and in such location as to avoid all possibility of drafts. Positive means, unaffected by atmospheric changes, must be adopted. The fan blower is now generally recognized as the only device which will satisfactorily meet these requirements. Proper results can only be obtained when it is installed to operate on the plenum system by forcing the air into the building. It is then both convenient and necessary to heat the air in transit to the rooms, but inasmuch as the temperature and air-supply requirements are likely to vary in the different rooms, some means more refined than is possible in factory heating must be employed for their proper regulation. Any one of three methods may be employed.

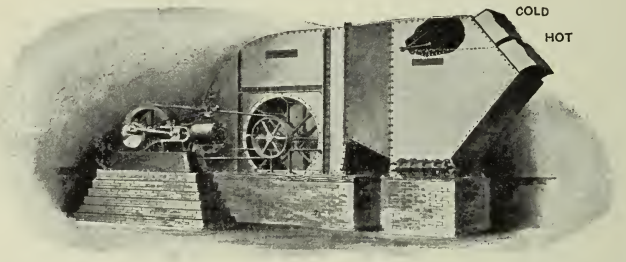


FIG. 18. HEATING AND VENTILATING APPARATUS FOR HOT AND COLD SYSTEM.

First.—The air, properly tempered, may be admitted in constant volume, and temperature regulation within the room secured by the use of direct radiators.

Second.— The air discharged from the fan at constant volume and temperature may be heated to any desired degree by supplementary steam coils placed within the supply ducts to the various rooms.

Third.— The entire heating surface may be concentrated in connection with the fan operating at constant speed, and so arranged that the air discharged through it will be heated, while other air by-passed round it still remains cool. A mixture of the warm and the cool air may then be made in any desired proportions to meet the exact requirements of the individual rooms.

An apparatus arranged in this general manner is shown in Fig. 18.

From the hot and cold outlets of such an apparatus separate ducts convey the air to the bases of the ventilating flues in the rooms, connecting as in the

illustration of a modern school building, presented in Fig. 19. The flues are in the interior walls, and are provided with openings 8 ft. or more above the floor. From each outlet the air is discharged at low velocity toward the cold outer walls, where it becomes slightly cooled, falls, and passes with slow movement back across the bodies of the occupants to the vent opening, which is at the floor level in the interior wall and near the supply flue.

With this arrangement, proper mixture of the warm and cool air at the flue base results from the action of mixing dampers operated by hand or automatically controlled. The arrangement of flue, hot and cold air pipes, and hand-operated mixing damper is shown in the sectional detail on the left.

This system is familiarly known as the *hot and cold system.* As ordinarily installed, the hot and cold air connections to each mixing damper are of equal size, so that whether the air be hot or cold, or a mixture of the two, its volume will remain constant.

Another arrangement of the hot and cold system with forced circulation consists in mixing the air at the heating chamber, and thence forcing it, properly tempered, though individual pipes to the ventilated rooms. In the design of the apparatus a tempering coil is provided, so that all the air is warmed to a temperature never exceeding 70 degrees. The main heater is enclosed in a brick chamber, and is supported above the floor at such height that a portion of the air may pass beneath without receiving supplementary heating. Individual automatic thermostats control the proportions of the mixture.

Although carbon-dioxide or carbonic-acid gas is the principal product of respiration, it is by no means the most harmful. The true evil of a vitiated atmosphere lies in its other constituent gases and micro-organisms, which, however, are difficult of determination. Fortunately they preserve a fairly constant proportion to the amount of carbonic acid present. As this gas is readily determinable, its relative amount in a given volume of air is generally accepted as a measure of its purity.

Cubic feet of air containing four parts of carbonic acid in 10,000 supplied per person.	Per Hour.	6000	4000	3000	2400	2000	1800	1714	1500	1200	1000	525	375	231
	Per Min.	100	66.6	50	40	33.3	30	28.6	25	20	16.6	9.1	6.2	3.8
Degree of vitiation of the air in the room.	Parts of carbonic acid in 10,000	5	5.5	6	6.5	7	7.33	7.5	8	9	10	15	20	30

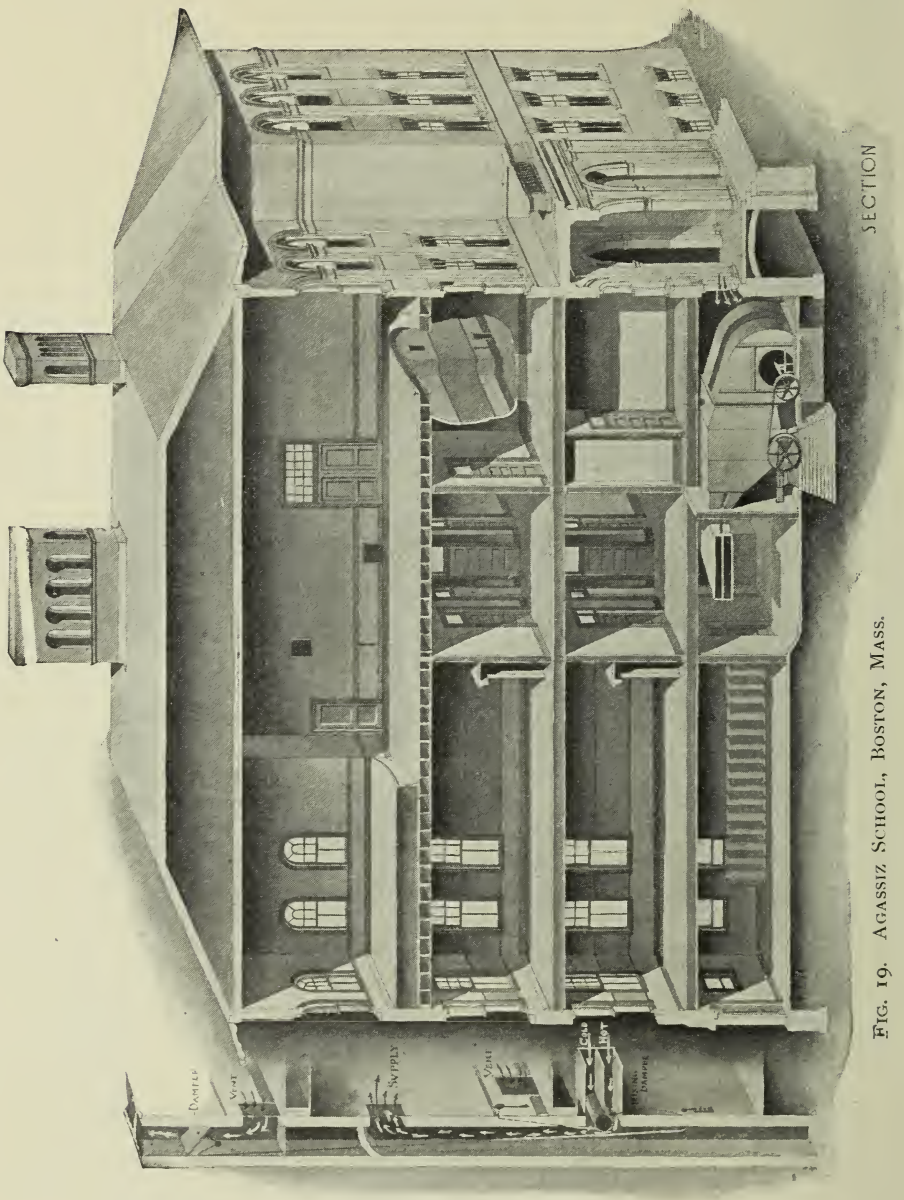


FIG. 19. AGASSIZ SCHOOL, BOSTON, MASS.

Assuming four parts of carbonic acid in 10,000 parts of air as the normal vitiation of the external atmosphere, and $\frac{6}{10}$ of a cubic foot per hour as the amount of carbonic acid exhaled by an average person, we have the accompanying requirements regarding the air supply necessary to maintain a given standard of purity within an apartment.

A supply of 30 cubic feet per person per minute, by which, under these conditions, the degree of vitiation is maintained at 7 33 parts carbonic acid in 10,000 of air, has been very generally accepted as the minimum volume permissible for the requirements of what may be considered good ventilation. This marks the practical limit of the most successful systems where mechanical means are *not* employed. In point of fact the average for such systems is well below this amount.

Under good school-room conditions, with a space allowance of 250 cubic feet per occupant, a supply of 50 cubic feet per minute, or 3,000 cubic feet per hour per individual, appears to mark the practical limit of success for imperceptible admission of air. This is equivalent to changing the entire volume within the room once in five minutes. Increased volumes call for increased care in the manner of introduction, as evidenced in lower velocities and the greater extent of inlet openings.

When we consider that every child has a money value, represented by the expenditure necessary to develop him to his present physical and mental condition, and a potential value as a future wage earner, which death or physical decline will make a total loss, the business aspect of school-room ventilation becomes evident.

Viewed from the financial standpoint alone, the actual cost of improved ventilation must be considered in its relation to the benefits derived therefrom. Obviously this cost must vary with the degree of ventilation, but the following figures from reports of the School Committee of the city of Boston have sufficient relative importance to be conclusive. During the school year ending June 30, 1893, the total expenditure per pupil in the Boston public schools, exclusive of furniture, repairs and new schoolhouses, was $25.10. Of this amount $0.945 was expended for fuel, so that the proportional cost of both heating and ventilating was only 3.75 per cent. of the total annual expense for the education of the child.

During the year covered by this report, the degree of air purity maintained in these schools was by no means up to the requirements of even fair ventilation. A conservative estimate would indicate that their heating alone might have been attained at an expense of about 82 cents per pupil. The ventila-

tion, such as it was, and for the hours of occupancy only, therefore cost about 12½ cents per pupil for the entire year. Fair ventilation, secured by the supply of 30 cubic feet of air per minute per pupil, would have cost not over 33 cents per pupil, making the total cost about $1.15 per pupil for both ventilation and heating. The additional expenditure necessary to bring the Boston schools up to a uniform standard of fair ventilation would therefore have entailed an increased annual expense for fuel of only 20½ cents per pupil, or less than ⅞ of one per cent. of the total annual expense of education.

Ordinary practice in school-house heating and ventilation, as exemplified in the illustration previously presented, limits the fan speed to that required to produce about one-half ounce, or ⅞ in. pressure per square inch, equivalent to a tip velocity of the wheel of about 3,600 ft. per minute. Duct velocities will then range from 1,200 or 1,500 up to 2,000 ft. per minute, flue velocities from 500 to 800 ft., and velocities of discharge to rooms from 300 to 400 ft.

All classes of buildings which may be properly included within the term "halls of audience" require substantially equal volumes of air to maintain equivalent degrees of purity, but their character, the per-capita space and the arrangements for seating largely control the manner of admission of air. Where the seats are permanently fixed and a plenum space can be provided beneath the floor, the air may be admitted therefrom through a multitude of small openings, thence pass upward across the persons of the occupants, and escape through ceiling openings. It thus becomes heated in transit and, in the case of an auditorium having little or no external exposure, must be admitted at a temperature measurably below that to be maintained within the room.

A counter direction of movement is sometimes provided, the air discharged by the supply fan being admitted through a perforated ceiling and drawn down through the floor by an auxiliary exhaust fan.

As a rule neither of these methods is admissible in a building diversified in its uses, like a city hall, for instance. For the smaller rooms, a so-called corridor system of distribution may be employed, the pipes being carried in spaces formed by furring down the corridor ceilings. Air is thus readily admitted above head level and discharged toward the outer walls. Leakage to the corridors and to the outer atmosphere usually meets the requirements of ventilation under the conditions of pressure maintained by the fan.

Plenum spaces beneath the audience chamber, which is almost universally placed above the offices, are here out of the question, and the simplest practicable arrangement consists in admitting air from wall registers beneath the

gallery, and upon either side of the stage, and then providing ventilation through wall registers near floor level, as well as through ceiling openings. The per-capita space is usually limited, and under the conditions it is difficult to imperceptibly admit sufficient volumes of air.

A church presents conditions peculiar to itself, for the per-capita space is usually large, the heat transmission losses are excessive, the time of occupancy is slight, and the period of heating is frequently limited to a few hours upon Sunday only. Although floor supply, subdivided for the individual pews, forms an ideal arrangement in such a building, it is frequently difficult of introduction and usually expensive.

A simpler arrangement, decidedly effective in its application, consists in admitting the air through wall registers, supplied from a system of piping beneath the floor. The greater part escapes though ventilating registers at floor level.

One of the most complicated problems presented to the heating and ventilating engineer is that of the modern theatre. Consisting as it does of three principal parts, namely, the auditorium proper, the stage and dressing-rooms, and the foyer, lobbies, stairways and connecting apartments, there is opportunity for constantly changing conditions as the performance progresses. It is seldom that the auditorium of a building of this character has any exposed walls. The effect of the occupants and of the lighting medium is therefore to increase the temperature to such an extent that the air must be admitted at a temperature below the normal, in order to maintain a comfortable standard.

Wall admission of air in large volumes is therefore impracticable, for the cooler air tends to fall with disastrous results to the audience. Floor or ceiling supply presents the only successful solution. As a rule the former method is more readily and economically introduced. A practical application is presented in Fig. 20.

Located in the space beneath the foyer and lobbies, at a point convenient to the fresh air supply from above the roof, is the heating apparatus. The air (heated or otherwise, as may be necessary), as it leaves the fan, passes in properly proportioned volumes in either direction along the passage, whence the greater part is allowed to escape to the space beneath the auditorium proper. In smaller volumes it is delivered to the first and second balconies through flues in the pilasters and through the hollow walls at the rear of the auditorium. Through the large flues, near the boxes, and upon either side of the auditorium, air passes to large wall registers, as shown in the section, and also to the space beneath the second balcony floor. The boxes are supplied through special

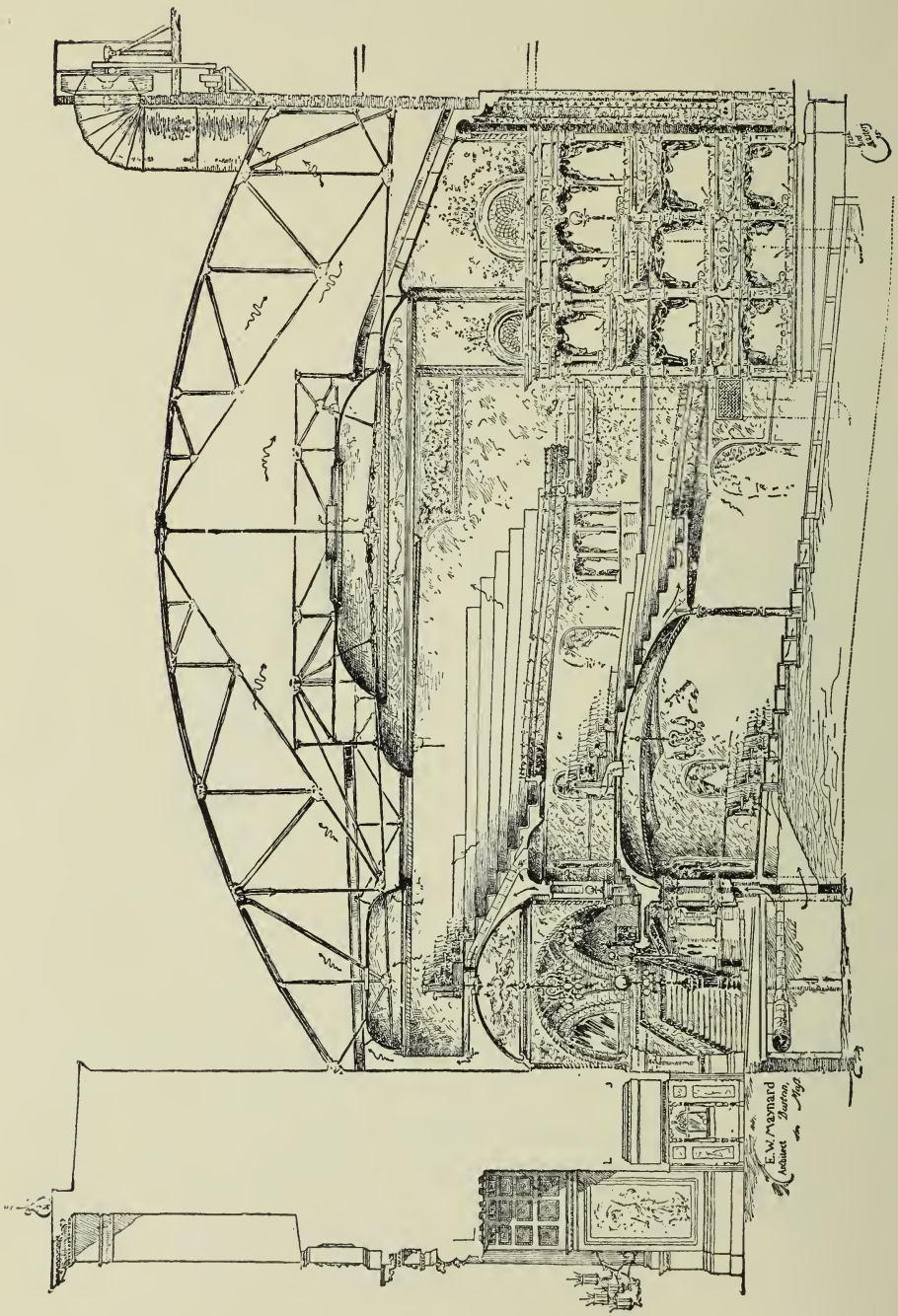


FIG. 20. CASTLE SQUARE THEATRE, BOSTON, MASS.

flues, which discharge into the passages with which they connect, whence the air enters the boxes beneath the doors, which are cut short, and passes across the occupants to the body of the house.

The principal supply for the auditorium — amounting to nearly 30,000 cubic feet per minute for the orchestra and orchestra circle alone, and as much more for the balconies — is admitted through the floors of these respective portions. In the case of the main floor, the space beneath it permits of the ready distribution of the air admitted thereto through the numerous openings in the basement partition wall.

The chair legs throughout the entire house are provided with special latticed castings, forming thereby a large number of air chambers to which air is discharged through the floor openings. The air thus passing through the floor openings at relatively high velocity is permitted to escape beneath the persons of the occupants with low and imperceptible movement, and then pass upward to the ceiling vents.

These vents, consisting of a central ceiling opening of moderate size and numerous smaller openings in the ceiling at the back of the second balcony, provide for a backward sweeping movement of the air across both first and second balconies, thereby securing the highest efficiency from a given volume of air. Special ventilation from the orchestra circle and the extreme rear of the first balcony is also indicated in the sectional view. From the roof space to which all this foul air passes, it is exhausted by a large electrically driven cone fan, located upon the roof above the stage and discharging freely into the atmosphere.

All escape of odors from the toilet and smoking rooms to other apartments is avoided by providing special and positive exhaust ventilation therefrom by means of an exhaust fan, located in the basement, which connects with a series of vertical flues. The same fan also serves to remove the heated air and odors from the kitchen and the boiler and dynamo rooms beneath the hotel.

The foyer is supplied with warm air through registers in the walls beneath the stairs, and is independently ventilated through its triple-domed ceiling. The stage is heated by means of steam coils at the back, suspended just beneath the floor, cast-iron gratings being provided through which the heated air may pass upward.

The temperature throughout the auditorium is regulated by a thermostat arranged to operate a by-pass damper on the heater, so that any desired temperature of the air passing to the conduit may be secured. To avoid trouble from too great and sudden cooling of the air, a minimum thermostat is also

introduced, which, as usually set, prevents the admission of air to the auditorium at a temperature lower than 65 degrees. With this arrangement this temperature is readily and uniformly maintained at 70 degrees throughout the house, while 30 cubic feet and over is supplied per minute to each occupant.

The conditions presented in a modern retail store are peculiar, in that the effect of constant passing through the doors is to admit large volumes of cold air, which very materially chill the adjacent portions of the store. This may be obviated to a very great extent by providing vestibules which are kept thoroughly warm by hot air supplied under pressure, so that all leakage is outward, and by introducing air at floor level beneath the counters facing or near the doors.

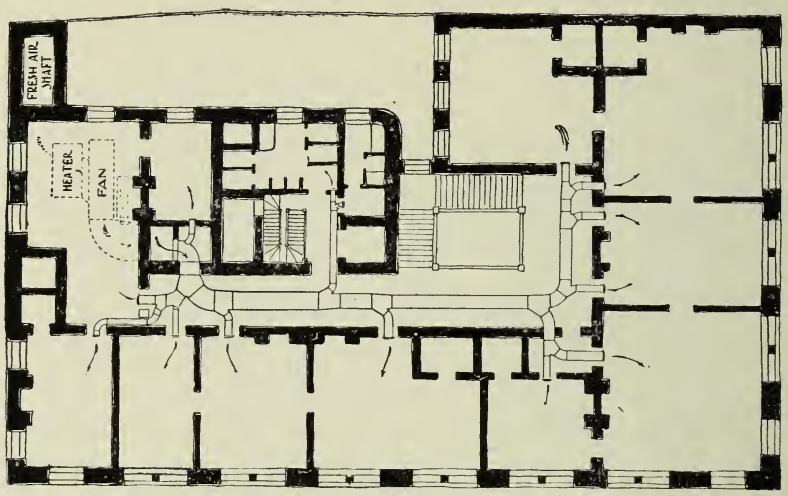


FIG. 21. HEATING SYSTEM IN THE OFFICE BUILDING OF THE AMERICAN BELL TELEPHONE CO., BOSTON, MASS.

Where the store is open in its character, the air may be delivered to the various floors through vertical brick flues located in the centre of the building or in the side walls, and distributed on individual floors by deflecting outlets.

In an office building of several stories an arrangement like that shown in Fig. 21 serves for thorough distribution, the apparatus being placed in the basement and discharging the air into a vertical flue with connections to horizontal ducts on each floor. These ducts are arranged on the corridor system previously mentioned. the admission to each room being made at or near the ceiling.

On ship-board the subject of proper ventilation is receiving the attention it has so long deserved, and systems have been introduced in our trans-Atlantic liners on the general principles already described.

The public at large is not slow to appreciate the material benefits of good ventilation, but its unsatisfactory experience with the movement of air by natural methods has almost led it to question whether good ventilation is attainable. Evidently positive means, acting independently of the weather, and capable of moving the required volumes, are absolutely necessary to success. The centrifugal fan best meets these conditions. It is furthermore a most important factor in the interdependent system which has been under discussion.

The particular features of this combined system of ventilation and heating may be thus summarized. The entire heating surface is centrally located, enclosed in a fire-proof casing, and placed under the control of a single individual, thereby avoiding the possibility of damage by leakage or freezing incident to a scattered system of steam piping and radiators. The heater itself is adapted for the use of either live or exhaust steam, and provision is made for utilizing the exhaust of the fan engine, thereby reducing the cost of operation to practically nothing. At all times ample and positive ventilation may be provided with air tempered to the desired degree. Absolute control may be had over the quality and quantity of air supplied. It may be filtered and cleansed, heated or cooled, dried or moistened at will. By means of the hot and cold system, the temperature of the air admitted to any given apartment may be instantly and radically changed without the employment of supplementary heating surface.

The pressure created within the building is sufficient to cause all leakage to be outward, preventing cold inward drafts and avoiding the possibility of drawing air from any polluting source within the building itself. By returning the air, using live steam in the heater and operating the fan at maximum speed, a building may be heated up with great rapidity, as is usually desirable in the morning.

The area of heating surface is only one-third to one-fifth that required with direct radiation, while the primary cost and operating expense of a fan is far less than that of any other device for moving the same amount of air.

The system is essentially a necessity in buildings occupied as halls of audience, and may be readily introduced in the mill and the factory. The increasing extension of electric power and fuel-gas distribution is making possible its application in all classes of buildings. Full appreciation of its advantages is therefore the best guarantee of its introduction.

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